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THE EFFECT OF BATCH QUALITY ON GLASS MELTING

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Glass-melting processes and the effect of batch quality on these processes are considered. An analysis is performed on the basis of a heat-engineering study of large-capacity glass-melting furnaces and mathematical modeling. Admissible single-impulse and multi-impulse deviations from a prescribed batch formula are estimated.

Highly efficient float-glass production lines and new machines for molding hollow articles that have replaced old glass-molding machines require substantial intensification of the performance of glass-melting furnaces. The need for increase furnace efficiency is also motivated by economic factors (growing prices of refractories, fuel, and power) and market factors (growing competition of manufacturers, stricter requirements imposed on product quality). The most essential factor in the production of sheet glass is the fact that it has become a basic product for making multiple window panes, laminated building and car glasses, and coated glasses (mirrors, energy-saving, decorative glass), i.e., articles that have to meet special requirements.

The use of float glass as a finished product has steadily decreased. In 2002 Russia produced 5.5 million m² of glass with coatings, 2.2 — mirrors, 6.3 — laminated glass, 17.0 — multiple window glasses, and 8.3 million m² hardened glass, which totals 65% of basic float glass produced.

The efficiency of furnaces for container and sheet glass has reached 2000 kg/m² of the working zone of the furnace and even more. The furnace campaign lasts 7 years and longer.

In these conditions, requirements imposed on raw materials and batches have grown perceptibly. The low quality of batches and initial materials is responsible for the fact that production of high-quality sheet and hollow glass in Russia is limited and substantial quantities of these products and materials are imported, which presents challenging competition to domestic manufacturers.

Let us analyze glass-melting processes and the effect of batch quality on glass melting based on some results published earlier [1].

Figure 1 presents a scheme of batch melting in a tank furnace.

Batch is charged into the furnace on top of glass melt at a velocity v (m/h). As the batch layer keeps moving along the furnace, its thickness changes due to its melting from above

and from beneath. The melt emerging on the top is running down from the tops of batch heaps, whereas the melt emerging beneath directly enters the glass melt. Within 1–2 min after batch loading, a viscous melt film of thickness 10 mm is formed on the surface of the batch, which impedes its complete melting. It can be assumed that the process of heating and melting of the batch proceeds in a quasistationary mode, when the melt formation rate is equal to the rate of its running down the batch heaps. The same assumption can be extended to the process of batch heating from beneath.

Let x and y be immobile coordinates. Then the following dependences are true for silica dissolving in a silicate melt (silicate and glass formation):

$$\frac{\partial w_{\text{SiO}_2}}{\partial t} = v \operatorname{grad} w_{\text{SiO}_2} - D \rho \Delta w_{\text{SiO}_2} - \left(w_{\text{SiO}_2}^b + \frac{1}{t - t_0} \int_{t_0}^t \sum_{j=1}^m K_j \prod_{i=1}^m w_{ij} \partial \tau \right), \quad (1)$$

where w_{SiO_2} is the weight content of SiO₂ in the melt; D is the diffusion coefficient; ρ is the melt density; $\Delta w_{\text{SiO}_2} = \frac{\partial^2 w_{\text{SiO}_2}}{\partial x^2} + \frac{\partial^2 w_{\text{SiO}_2}}{\partial y^2}$ is the Laplace operator; $w_{\text{SiO}_2}^b$ is the weight content of SiO₂ in the batch; t is the current time; t_0 is

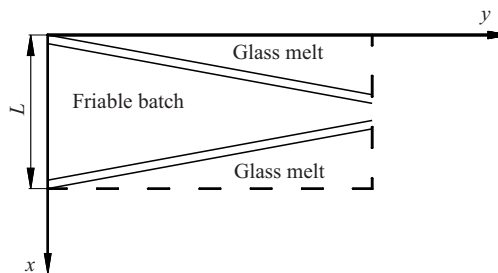


Fig. 1. Batch melting scheme.

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the time of charging start; $\int_{t_0}^t \sum_{j=1}^m K_i \prod_{i=1}^m w_{ij} \partial \tau$ is the quantity of

SiO_2 fixed as a result of silicate-formation reactions; m is the number of components; K_i is the constant of the i th reaction of silicate formation.

Equation (1) can be complemented by the heat exchange equation:

$$\rho c' \frac{\partial T}{\partial t} = \text{div} (\lambda \text{grad } T - q D \rho \text{grad } w_p) - \rho v \text{grad } H,$$

where c' is the heat capacity of the mixture (silicates + quartz + melt); $c' = \varphi_{\text{SiO}_2} w_{\text{SiO}_2} + \varphi_m w_m$ (φ_{SiO_2} and φ_m are the contents of SiO_2 and melt in the silicates + quartz mixture); λ is the effective thermal conductivity of the melt; q is the specific isothermic transfer heat; w_m is the weight content of the melt in the mixture with dissolved SiO_2 particles; H is the enthalpy of melt mixture, $H = H_{\text{SiO}_2} w_{\text{SiO}_2} + H_m w_m$.

Equation (1) was analyzed using data obtained in a heat-engineering study of a float-line furnace (Saratov Technical Glass Works) and a vertical drawing line (Mekhteklo Lisi-chanskii Works).

The rate of change of SiO_2 content in the longitudinal section of the furnace is approximated by the dependence

$$w_{\text{SiO}_2} = 13.75 + 4.5x + 0.14y - 1.2t - 7.8x^2 + 1.6t^2, \\ v \approx 8 - 15 \text{ m/h}, \quad D \approx 10^{-7} \text{ cm}^2/\text{sec}.$$

Then the first term on the right-hand side of Eq. (1) has the order $v \frac{\partial w_{\text{SiO}_2}}{\partial x} \sim 40 - 80$; $v \frac{\partial w_{\text{SiO}_2}}{\partial y} \sim 150 - 250$, the second term has 10^{-4} , and the fourth term $10 - 30$.

The estimate given above makes it possible to simplify the problem to a unidimensional case and to obtain the following transcendent equation with respect to

$$\beta = \frac{S}{\sqrt{2t}},$$

where $x = S$ is the coordinate of the glass melt – friable batch boundary:

$$\frac{\lambda}{\sqrt{1/D_b}} (T_m - T_{b0}) - \frac{\exp(-\beta^2 / 2D_b)}{\exp(\beta / 2D_b)} = \\ = j\rho \sqrt{\frac{\pi}{2}} \beta + \frac{\lambda_g}{\sqrt{1/D_g}} (T_{g0} - T_m) \exp \frac{1}{\sqrt{2/D_g}}, \quad (2)$$

where j is the specific heat of batch melting.

The following data were assumed for the calculation of the melting zone boundary:

- the batch-charging velocity for the float-line furnace is 16 m/h and for the vertical-drawing line 10 m/h.
- for the batch composition corresponding to the glass formula: $\lambda_b = 0.1914 \text{ W}/(\text{m} \cdot \text{K})$, $\lambda_g = 132 \text{ W}/(\text{m} \cdot \text{K})$, and $j = 8.36 \text{ J/kg}$.
- the batch layer thickness $(2/3)L = 0.2 \text{ m}$, $T_m = 1123 \text{ K}$.

Then based on Eq. (2) we obtain that the duration of batch heating up to the melting point is approximately 0.67 h. Considering the batch charging velocity in the Lisi-chanskii Works furnace, this corresponds to the melting zone boundary of 6.7 m (the 2nd burner zone), for the Saratovskii Works furnace it is 11.4 m (between the 3rd and 4th burners).

The initial parameters and, consequently, calculation results depend on the melting temperature and stability of the batch composition. Under a constant melting temperature, a 2% deviation in SiO_2 content changes the calculated melting zone boundary by $\pm 1.3 \text{ m}$.

It is known that a steady position of the melting zone boundary is one of the most important factors for maintaining a stable melting regime and ensuring glass melt quality.

The stability of the chemical composition of the batch, other terms being equal, depends on the accuracy of component proportioning. The proportioning accuracy, in turn, depends on the proportioner system design and the quality of the electronic control system. Furthermore, a preset batch composition may differ from an actual composition due to the fact that the materials (batch components), as a rule, introduce several glass components (oxides) simultaneously.

It is possible to define more strictly the following technological and physical limitations in estimating the proportioning accuracy [2 – 4]:

- rating of glass components;
- some glass components are introduced by means of several batch material components;
- in the system of equations describing the dependence of the batch composition on a preset glass composition, the quantity of unknown values may differ from the number of equations (the case of a nonquadratic matrix);
- the solution of the system of glass composition – batch composition equations should be non-negative;
- it is necessary to take into account mechanical entrainment of batch components and volatilization of glass components from melted glass;
- compositions of materials, batch, and glass are influenced by errors depending on measurement methods and instrumental errors.

The material composition – batch composition dependence is described by the following relationship:

$$Y = AX,$$

where $Y = \{y_i\}_n$ is the n -dimensional vector of the batch composition; $X = \{x_j\}_m$ is the m -dimensional vector of material portions; $A = \{a_{ij}\}$ is the matrix of dimensionality of the material composition $n \times m$.

Passing on to a differential form and rejecting 2nd order terms, we will obtain

$$\sigma_i^2 = \sum_{j=1}^n [(\hat{A}_j \sigma_{ij})^2 + (\hat{x}_{ij} \sigma_j)^2], \quad (3)$$

where σ_i is the mean quadratic deviation $\Delta \hat{y}_{ij}$, $\Delta \hat{y}_{ij} =$

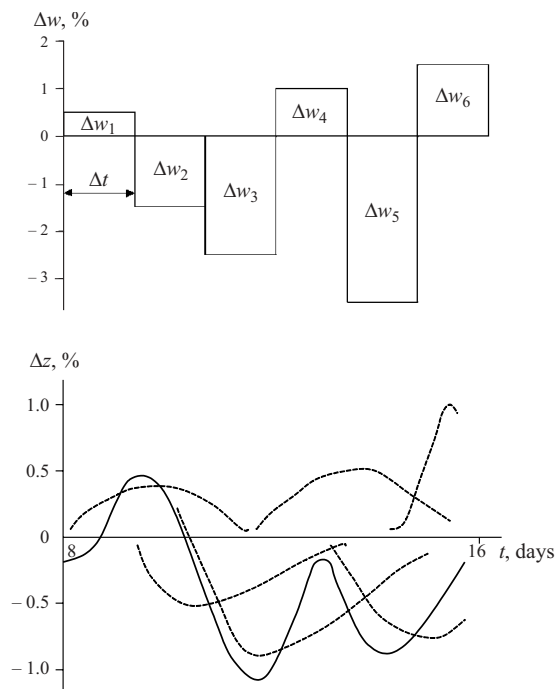


Fig. 2. Variations in SiO_2 content in the batch Δw within time period Δt and respective variations in SiO_2 content in glass Δz : dashed curves) variations in SiO_2 content in glass for a single impulse change in SiO_2 content in the batch; solid curves) variations in SiO_2 content in glass for multi-impulse change in SiO_2 content in the batch.

$\sum_{j=1}^n (\hat{A}_j \Delta \hat{x}_{ij} + \Delta \hat{A}_j \hat{x}_{ij})$; \hat{A}_j is the measured value of the content of the j th material component; $\sigma_{ij} = \frac{1}{3} \Delta \hat{x}_{ij} \alpha_j$ (α_j is the accuracy of determining the content of the main oxides in the j th material component); $\Delta \hat{x}_{ij}$ is the absolute error of measuring the content of the i th oxide in the j th batch component; $\Delta \hat{A}_j$ is the absolute error of measuring the weight of the j th material component; x_{ij} is the measured content of the i th oxide in the j th material component; $\sigma_j = \frac{1}{3} \Delta \hat{A}_j x_{j \max}$.

Calculation based on relationship (3) was carried out for two types of proportioners used in the Russian glass industry: a DVST proportioner (with a lever system and weight fixation based on the indicator pointer) designed by the Veda Company and a DSI strain-measuring gauge (with a MBUD microprocessor controlling block) designed by the Institute of Glass JSC and the Stromizmeritel' Company (Table 1).

TABLE 1

Proportioner	Weighing error, % of the maximum weighing limit					
	sand	dolomite	chalk	sulfate	soda	feldspar
DVST	0.26	0.66	0.83	0.67	0.32	1.06
DSI	0.12	0.16	0.31	0.28	0.14	0.32

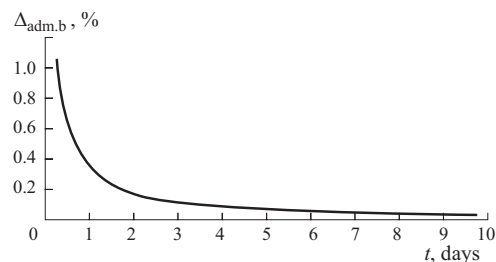


Fig. 3. Dynamics of admissible changes in the batch composition.

It can be seen that only the DSI proportioner ensures proportioning accuracy meeting the requirements of the Technical regulations for sheet and container glass factories.

A single impulse change in a batch composition was considered above. For a multi-impulse deviation in SiO_2 content in a batch, another approach to estimating an admissible deviation level is possible [5].

Figure 2 shows fluctuations in SiO_2 content in a batch and respective fluctuations in SiO_2 content in glass produced at the Tokmakskii Works:

$$\Delta_{\text{adm.b}} = \frac{\Delta_{\text{adm.g}}}{\sqrt{\sum_{c=1}^n \Delta f_{\Delta t}^2 (i \Delta t)}}$$

where $\Delta_{\text{adm.b}}$ and $\Delta_{\text{adm.g}}$ are admissible SiO_2 fluctuations in the batch and in glass; $\Delta f_{\Delta t}$ is the change in the SiO_2 content in glass (a result of modeling the homogenization process); i is the number of impulses.

The calculation results are indicated in Fig. 3.

Thus, a single deviation (one batch portion) up to 1% can be permitted due to the homogenizing capacity of the furnace. As a rule, the deviation should not exceed 0.15%. Such weighing accuracy can be provided only by the DSI proportioner or imported dosing machines with a class of accuracy not lower than that of the DSI.

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